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An assessment of anaerobic digestion capacity in Bangladesh

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ABSTRACT

This work scopes the potential for existing common feedstocks to be used in existing types of anaerobic digester units to produce biogas in Bangladesh. A preliminary study identified three commonly occurring scenarios of smallholdings with cattle, poultry farms and daily cattle markets, which produce dung, poultry litter, and dung mixed with rice straw, respectively. This third feedstock is proposed as a novel and significant newly recognised prevalent source. The main study involved carrying out surveys of representative samples of each of these ($N=125$, 125, and 30) for the district of Gazipur in order to determine the distribution of herd and flock sizes, and thus the relevant biogas plant types and potential yields. The results were scaled up for nationwide figures, which approximated the total potential biogas energy from these feedstock types at 240×10^6 MJ (240 TJ) per day, or 66.7×10^6 kWh, which in principle could meet the current cooking energy requirements of 30 million people in Bangladesh. Of this, 70% of the potential energy from AD could come from cattle feedstock (with 87% of this from domestic-sized plant); 16% from poultry feedstock (with 63% of this from medium-sized plant); and 14% from rice straw bedding from cattle markets (all requiring very large or extremely large plant). There is potential for around 2 million domestic units, 340,000 medium units and 19,000 large units, as well as 500 very large units that might be more suited for larger users such as businesses, schools or hospitals.

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1. Introduction

1.1. Geographical information for Bangladesh

Bangladesh is one of the least developed and most densely populated countries in the world [1], with a land area of 147,570 km^2 and a population density of 1063 people per km^2, with an income per capita 1/100th of the UK [2]. A humid, low-lying, alluvial region, Bangladesh is composed mainly of the great combined delta of the Ganges, Brahmaputra, and Meghna rivers. Except for the Chittagong Hills along the Myanmar border, most of the country is less than 90 m above sea level.

1.2. Energy status

The population of over 144 million people faces severe problems of environmental degradation, shortage of food supply, reduction of soil fertility and scarcity of energy [3]. The economy of Bangladesh is agriculture-based, with more than 60% of the workforce engaged in agriculture [4], and agriculture contributes about half of the Gross Domestic Product (GDP). Per capita electricity consumption is only 146.5 kWh in Bangladesh, whereas in India it is 480.5 kWh, and in Pakistan, it is 456.2 kWh, and for developed countries the average per capita electricity consumption is 8009.5 kWh [5].

Except for natural gas found along its eastern border, limited quantities of oil in the Bay of Bengal, coal, and some uranium, Bangladesh possesses few fossil fuel reserves. More than 55% of the country's energy requirement comes from traditional biomass energy sources, which are crop residues, twigs, leaves, firewood and dung cake [6]. Traditional biomass energy is used mostly for cooking. Excessive use of biomass energy causes deforestation and in the long run increases the likelihood of environmental disasters like cyclones and floods, compromising agricultural productivity and economical development [6].

Commercial energy consumption comes from around 66% natural gas, met by the country's reserves of natural gas, and the other 34% by oil and limited amounts of hydropower and coal. The gas is used in the manufacturing of fertiliser, generation of electricity, direct use in certain industries, and as cooking fuel in major urban areas. Economically, it is not feasible to supply the gas to the rural areas through pipelines. Petroleum products such as high speed diesel oil and superior kerosene oil are the main fuel for transport and rural lighting [4].

1.3. Waste scenario and management

General waste management in Bangladesh is known to require further improvements to be effective. To illustrate this point we note that every day 3500 t of waste is produced in Dhaka, the capital of Bangladesh. This includes Municipal Solid Waste (MSW), agricultural waste and a minor amount of animal waste (cattle dung and poultry litter) [7]. Although 511,000 t of waste are disposed at simple controlled landfills near Dhaka annually, a further 509,248 t per year are 'lost' or illegally dumped [8]. for example, only 42% of waste for disposal in landfill is collected: much can be found on roadsides, near open drains, and in the low-lying areas of the city [9]. The dumping of waste has led to major problems such as transmission of diseases, greenhouse gas emissions (GHG) and pollution of ground water [10].

Most non-urban families in Bangladesh have a 'smallholding', including a few cattle where possible. The dung is collected and dried as a cake for fuel for cooking. Open storage of cow dung in smallholdings is common, creating breeding grounds for mosquitoes and disease vectors [11]. Some families have a poultry farm; the litter is usually disposed of at the edge of nearby fields and can cause environmental and land pollution. Inadequate collection and uncontrolled disposal of waste generally creates a health hazard to inhabitants and the environment in Bangladesh [12]. A small amount of cattle dung and poultry litter is reportedly used as a biogas feedstock [6], which shows that such a pathway can in principle work. The waste from the cattle markets, comprising of dung, rice straw and urine and which is increasing year by year, is currently landfilled.

Apart from landfill, the two major common practices relating to organic waste in Bangladesh are composting of household waste and anaerobic digestion of animal manure. Both serve to stabilise organic waste, make it hygienic, and reduce its mass. Furthermore, they facilitate the return to the earth of organic compounds and some nutrients. Anaerobic digestion processes can also be designed to allow the collection of a useful amount of biogas, even when waste management is the main purpose. Composting and digestion can be used as complementary approaches, depending on parameters such as the kind and variety of waste material; anaerobic and aerobic steps may also be combined in one treatment facility [13]. Climate change has been a significant recent driver leading to a move away from the landfilling of biodegradable wastes (a major source of methane emissions) and to a renewed focus on energy recovery from waste [14]. Due to these multiple potential benefits of waste management, GHG control, potential energy production and possible nutrient production, AD has become an important option for developed and developing countries.

1.4. Anaerobic digestion

Anaerobic digestion (AD) is a biological process of the breakdown of organic matter by naturally occurring bacteria in the absence of air, and this produces biogas and a solid digestate. Biogas comprises of mostly methane and carbon dioxide with a small amount of hydrogen sulphide and hydrogen. Depending on the type of input material, the residual solid matter or digestate can be a nutrient-rich bio-fertiliser [15]. According to a report by the Bangladesh Centre for Advance Studies [16], the 8.44 million households of Bangladesh have 22.29 million cattle and buffalo, and there are 116,000 poultry farms which produce 22,139 t of litter per day. Traditional use of dung and litter has a big impact on the environment and cultivable land in Bangladesh because when it is dumped on low ground adjoining dwelling areas it causes them to be affected by smell, dust and surface water pollution [17]. Bangladesh already has nearly 40,000 domestic biogas plants using cow dung or poultry litter, but the full potential has been estimated at 3 million plants [6]. The traditional use of biomass for cooking or the burning of renewably harvested fuel wood has often been assumed to be greenhouse gas neutral as eventually all the CO_2 will be recycled and taken up by vegetation in the next growing season. But this process is not emissions-neutral unless the biomass fuel is burnt efficiently and completely, and burning of biomass fuels in stoves typically achieves only about 10–25% overall efficiencies, emitting a significant portion of pollution in the form of products of incomplete combustion (PIC) that have higher global warming impact per carbon atom than CO_2. Biogas derived from AD using cow dung as feedstock when used in stoves is cleaner and has a higher combustion efficiency of around 60%.

Bangladesh has a suitable climate for biogas production. The ideal temperature for biogas is around 35 °C. The temperature in Bangladesh usually varies from 6 °C to 40 °C, but the internal temperature of a biogas digester in Bangladesh usually remains at 22 °C to 30 °C, which is very near to the optimum requirement [18]. Suitable raw feedstocks for biogas such as cow dung and poultry litter are easily and cheaply available throughout the country.

The potential for mass deployment of domestic AD plants is very promising. Government and micro-finance companies already support such schemes. The use of AD could supply a much-needed energy resource for domestic consumption for cooking, as well as bio-fertiliser to enrich the farm land. It would also reduce deforestation by displacing wood fuel, and improve air quality in rural homes by avoiding contributions caused by incomplete combustion of solid fuels. These AD plants would be situated in rural farm areas where there is no realistic option for extending natural gas supply, on smallholdings where the energy would be directly used.

The common use of AD biogas in Bangladesh would also make a significant contribution to the reduction of greenhouse gases, which could provide some income via the Clean Development Mechanism (CDM). However, this approach would require appropriate calculation of baseline carbon emissions.

The focus of this study is the determination of the potential energy contribution and energy patterns of small and medium AD systems in Bangladesh from common feedstocks and common scenarios.

2. Overall methodology

To determine the scope of currently available AD opportunities in Bangladesh, three strands of methodology were developed. Firstly, preliminary exploratory investigations were used to determine the most common scenarios in the country which could provide appropriate feedstocks. Secondly, representative surveys were undertaken in one district of Bangladesh to determine the size distributions of potential AD plant for each scenario in that district. Thirdly, the results were scaled up for nationwide figures. More details of each are given in the appropriate sections below.

3. Exploratory study to determine most common scenarios

In order to first determine the most common scenarios which could provide immediate opportunities for AD, it was decided to obtain an overview of common organic waste streams and existing AD practices of Bangladesh through initial exploratory field visits and meetings with key government and non-governmental organisations of Bangladesh. These included Grameen Shakti (GS), Advance Engineering (AE), Bangladesh Council for Scientific and Industrial Research (BCSIR), Netherland Development Organization (SNV) and Infrastructural Development Company Limited (IDCOL). Those organisations are key sources of related data and are deeply involved with AD research through contributing field and laboratory facilities in Bangladesh. Grameen Shakti also provided access to a number of AD sites for visits for this research.

From these explorations and also literature searches it was found that common scenarios included smallholdings with cattle, poultry farms, municipal waste (i.e. the organic elements) and water hyacinths. However, it was recognised that municipal waste could not provide the reliable homogeneity and constant supply required for effective AD, and that water hyacinths are not available all year round (although they are a prolific source of material at certain times of the year). One of the authors also individually proposed a new scenario: daily cattle markets held in towns, which produce regular amounts of rice straw mixed with dung. The final three common scenarios which showed most promise were then surveyed: cattle from smallholdings, poultry farms and cattle markets.

From the exploratory work it was noted that the daily AD feedstock produced and collected per animal could vary significantly depending on their age and condition, food habits, and whether left free to wander or kept inside. For consistent calculations in this work, the secondary data summarised in Table 1 was used. The cattle and poultry data come from field experience documented by the large scale practitioners in Bangladesh, Grameen Shakti. The cattle market data was obtained by the author in collaboration with engineers from Advance Engineering, and is reported in full elsewhere [28]. In the daily cattle markets, the dung produced becomes mixed with rice straw and urine, producing approximately five kilos of mixed material for every kilo of dung. This particular material produces more methane per kilogram of feedstock than dung alone, giving a huge figure of 95 MJ per animal per day of potential methane via AD [28] (see Table 1).

Table 1
Secondary information on typical AD feedstock production rates for cattle, poultry and cattle in markets.

AD feedstock sources	Feedstock production (kg/animal/day)	AD gas yield rate (MJ/kg)	Potential AD (MJ/animal/day)
Cattle dung	10[a]	0.8	8.1[a]
Poultry litter	0.1[a]	1.7	0.16[b]
Cattle market waste[c]	35[d]	2.7[d]	95

[a] Available in a book published by leading practitioners Grameen Shakti: [23].
[b] Obtained in a personal communication from M.A. Gorfan of Grameen Shakti [23].
[c] Approximately 20% dung and 80% (straw + urine) was observed to be present.
[d] Obtained by the author with assistance from Advance Engineering, as reported elsewhere [28].

4. Surveys of smallholdings, poultry farms and cattle markets

A survey to identify the feedstock capacity of Gazipur district for the three scenarios was carried out. Bangladesh consists of 64 districts with 507 sub-districts, and each sub-district has a large number of cattle smallholdings and poultry farms of varying capacity [19]. Moreover, reliable quantitative data for each district are not available. Research conducted by Wilson et al., [20] found that quantitative data on waste research were generally scarce and unreliable in developing countries. A private communication with the lead author confirmed that this scarcity included data on animal wastes. It was thus decided to collect primary data via surveys across each sub-district of one district, and Gazipur was chosen since one of the authors was very familiar with it. A total of 280 sampling surveys were carried out: for each of the five sub-districts this included 25 cattle smallholdings, 25 poultry farms, and all known cattle markets.

Each sub-district is made up of several hundred Unions (which in turn are made up of small communities). In each sub-district, Unions representing more or less the geographic centre, north, south, east and west areas were selected, and 5 smallholdings and 5 poultry farms were randomly selected in each of those. All known cattle markets were visited ($N=30$).

During the survey, smallholdings with a cattle population of less than 3 were not included because the daily requirement of biogas for cooking purposes for an average sized (5 person [23]) family is 2 m^3, requiring at least 5 cattle. However, smallholdings of 3–4 cattle were also included in this survey for two reasons. Firstly, they can produce around 1–1.5 m^3 of biogas daily, meeting the requirements of a small family (3–4 people/family) [23]. Secondly, the exploratory study revealed that there are a number of 2 m^3 AD plants in Bangladesh currently operating which only have 3–4 cattle per smallholding. Additional information was collected for each site in the survey such as if there is an existing

on-site biogas plant, the plant size, the food habits of the animals, and any uses of gas and slurry and other products.

It was decided to use three AD plant sizes for reference as they are generally available: domestic (D) rated for 2–5 m^3, medium (M) rated for 5–25 m^3 and large (L) rated for 25–150 m^3 of biogas daily [21]. In fact our data was found later to imply the usefulness of both a smaller and two larger plant, rated at <2 m^3 and 1–2000 m^3, 2–7000 m^3 respectively, and which we labelled as 'small domestic', 'very' and 'extremely' large.

4.1. Survey results of cattle in smallholdings

In each of five sub-districts of Gazipur, 25 smallholdings were randomly surveyed, altogether showing a total cattle population of 1118 cattle across 125 smallholdings. The herd size distribution is shown in Table 2 below.

Table 2 shows that most (81%) of cattle smallholdings have a cattle population of 3–10, which is useful for planning appropriately sized AD plants. In terms of cumulative quartiles, 25% of the smallholdings were found to have ≤ 4 cattle, 50% of them ≤ 5 cattle, and 75% ≤ 8 cattle. The highest number of cattle found in a smallholding was 54. Any with less than 3 cattle were excluded for our purposes, and are thus not represented in this data.

Table 3 shows the distribution of smallholdings by potential AD plant size. The daily energy requirement for cooking purposes is 44 MJ/ household of 5 members [22]. Using the value of 8.1 MJ of biogas/animal daily [23] (see also Table 1), our survey result shows that 29% of smallholdings have a capacity to produce up to 2 m^3 of biogas daily (i.e. less than the size of the smallest commonly available AD unit) and can generate only 29 MJ of energy. This is only sufficient for a family which is smaller than average (i.e. 3–4 instead of 5), but on the basis of this data indicating the availability and usefulness of this new smaller category of plant, we added it to our considerations and labelled it 'small domestic' plant. The survey data showed that an additional 58% of cattle smallholdings have potential for domestic sized biogas plant with yield rates of 2–5 m^3 daily (domestic size).

A further 13% of smallholdings were found to yield potential capacity of 5–25 m^3 (medium size), with a daily average of 232 MJ/smallholding. This amount of energy can meet the cooking energy requirements for up to 5 families collectively.

Note that these calculations are based on a published yield capacity which is appropriate for optimal operational conditions (10 kg per cattle per day, [23]).

Fig. 1 introduces cumulative information not only for the herd sizes but also for the energy outputs possible. It illustrates useful combinations of information e.g. that 50% of AD energy capacity of cattle smallholdings comes from cattle those with ≤ 9 cattle, which is 80% of the total number of farms. This means that even if only domestic sized facilities were used, 50% of the potential could be captured, and that it would be spread out over a large number of rural users. Fig. 1 also shows that 25% of the AD energy capacity could be captured at only a few – 10% – of the (larger) farms.

4.2. Survey results for poultry farms

The poultry population of Gazipur was surveyed via random choices of 25 poultry farms in each of 5 sub-districts. The survey results for the 439,950 birds over a total of $N=125$ farms are summarised in Table 4 and Fig. 2.

From Table 4 it can be shown that 76% of the poultry farms have a poultry population of 4000 or less. In terms of cumulative quartiles, 25% of the farms surveyed had a bird population of <1000 birds, 50% had <1900 birds and 75% of the farms had a bird population of ≤ 4000. The highest bird population found was 20,000 birds.

Table 5 shows the distribution of smallholdings by potential AD rated plant size. Using the value of 0.1 kg feedstock production per bird per day [26] (and see Table 1), then only 7% of the farms are suitable for domestic sized biogas plant, showing an average capacity of 93 MJ/farm. Most (63%) of the poultry farms are suited

Table 2
The number of smallholdings with different sized herds in Gazipur district ($N=125$. Note that only those with 3 or more cattle were recorded.).

Number of cattle	No. of smallholdings	% smallholdings
3–5	54	43
6–10	48	38
11–15	8	7
16–20	5	4
>21	10	8
Total	**125**	**100**

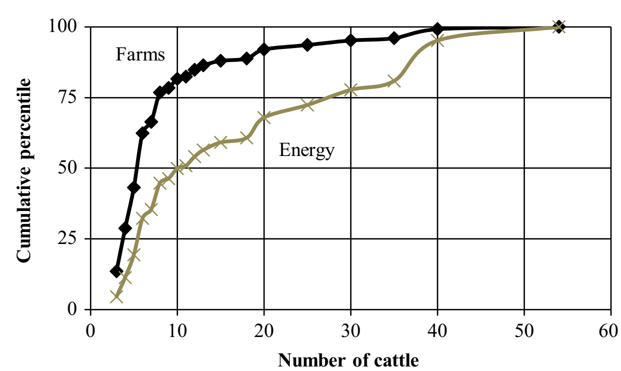

Fig. 1. Cumulative percentile of the number of smallholdings ('farms') and their energy potential with respect to the number of cattle on each farm, for Gazipur district (from survey results).

Table 3
Cattle smallholding distribution by AD plant size (from survey results, $N=125$) in Gazipur district.

AD type	Rated[a] biogas capacity (m^3)	% of smallholdings	Average no. cattle/ smallholding	Average daily MJ/ smallholding
Small domestic	(<2)	29	3.5	29
Domestic	(2–5)	58	7	57
Medium	(5–25)	13	28.6	232

[a] Rated capacity values are as introduced in Section 4, pp 5.

Table 4
The number of poultry farms with different sized flocks (from survey results, $N=125$) in Gazipur district.

Number of birds	Number of poultry farms	% of poultry farms
<1000	15	12
1000–2000	55	44
2001–3000	15	12
3001–4000	10	8
4001–5000	8	7
5001–10,000	13	10
$>$ **10,000**	**9**	7
Total	**125**	**100**

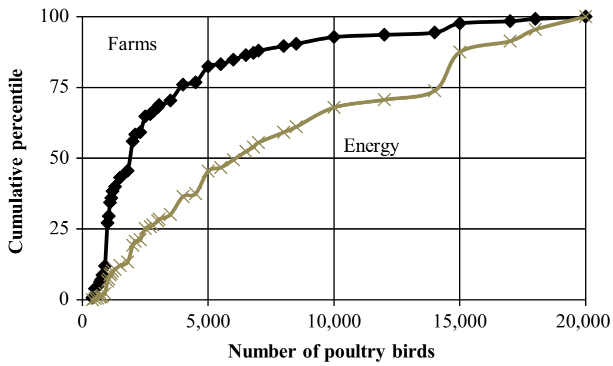

Fig. 2. Cumulative percentile of the number of poultry farms and their energy potential with respect to the number of birds on each farm, for Gazipur district (from survey results).

Table 5
Distribution of poultry farms by AD plant size (from survey results, $N=125$) in Gazipur district.

AD Type	Rated[a] biogas yield (m^3)	% of farms	Average no. birds/farm	Average MJ/farm
Domestic	2–5	7	572	93
Medium	5–25	63	1614	270
Large	25–150	30	8305	1399

[a] Rated values are as introduced in Section 4, pp 5.

for a medium sized AD plant, showing an average energy capacity of 270 MJ/ day. A further 30% of the poultry farms are suitable for a large AD plant, averaging 1400 MJ per day which could be suited for commercial or small industrial use.

Given that 44 MJ of energy is considered the requirement for domestic cooking for a medium sized family, Table 5 suggests the average farms suited for 'domestic' sized AD plants would actually be producing enough gas for two families (93 MJ/day). Thus, such farms could in practice provide energy to another family, or develop some new entrepreneurial activity based on it. Similarly, most of the poultry farms have the potential for medium or large-scale AD which could provide cooking gas for many families, or make significant contributions to businesses located on site or nearby.

Fig. 2 introduces cumulative information not only for the flock sizes but also for the potential energy outputs. It is useful for determining which sized farms and thus sizes of AD plant should be targeted for different reasons. For example, it shows that most of the energy – 60% – can be captured from as few as 25% of the farms (the largest ones), using large scale plants.

4.3. Survey results of cattle markets

All the known cattle markets in Gazipur district, $N=30$, were surveyed to determine the number of cattle they serviced and the tonnage of waste rice straw bedding they produced daily. On average, each daily market had 796 cattle and produced 28 t of waste i.e. 35 kg per head of cattle daily. Cumulative percentile figures were calculated to show that 25% of the markets had a cattle population of ≤ 400; 50% had a cattle population of ≤ 500 and 75% had cattle populations of ≤ 1000 respectively. The highest cattle market population was found to be 2000.

Table 6 shows the biogas yield and energy generating capacity of cattle market rice straw. Results indicated that each cow can produce 94 MJ of energy, which is more than double that of an average-sized family's energy requirements for cooking. This figure of 95 MJ/cow is considerably larger than for a smallholding

Table 6
The distribution of cattle markets by potential AD plant size (from survey results, $N=30$) for Gazipur district.

AD type	Daily biogas yield (m^3)	% of markets	Average no. cattle/ market	Average MJ/ market
Very large	1000–2000	53	390	36,750
Extremely large	2000–7000	47	1150	108,000

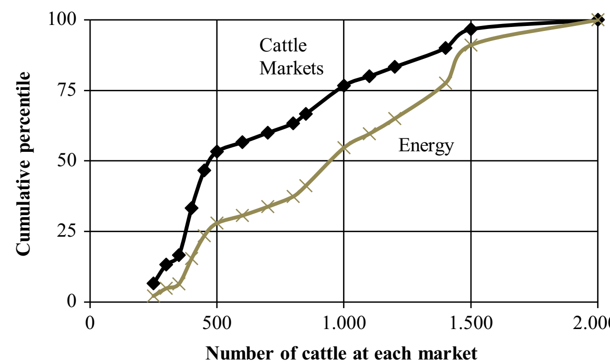

Fig. 3. Cumulative percentile of the number of cattle markets and their energy potential with respect to the number of cattle in each, for Gazipur district (from survey results).

cow because in the market each kilo of dung is combined with approximately 4 kilos of straw and urine mixture. The energy potentially generated at each site from this source was shown to be very significant, so that even the existing 'large' sized domestic AD plants were 5–6 times too small for this scenario. Instead, a new category of 'very large' AD plant, rated at 1000–2000 m^3 had to be created to acknowledge the requirements, and a further category of 'extremely large' for markets which had a capacity of 1000–2000 m^3. Nearly half of the markets required the latter size of plant. This is an important finding of our work: that there exists an existing, regular, homogenous and suitable feedstock for AD production of biogas on a scale not previously developed, but typically present exactly where the need is for larger-scale energy production – in towns. Thus, the energy could be used for businesses (such as those at the markets) or for easy distribution to local homes. The average energy capacity of these extra large AD plants is around 108,000 MJ.

Fig. 3 represents cumulative information for both the sizes of the markets and the potential energy outputs. It shows that approximately 50% of cattle markets had 500 or fewer cattle and 25% had a cattle population of more than 1000.

The total energy capacity of the cattle market rice straw feedstock from all 30 markets is 2,100,000 MJ, giving an average cattle market energy capacity of 70,000 MJ/day. Such high numbers indicate that this feedstock has potential for not only biogas production but also secondary production of electricity.

5. Scaling up to determine nationwide potentials

The numbers obtained for the district of Gazipur were scaled up for the country of Bangladesh using multipliers based on the relative number of cattle, poultry and cattle markets in both. Table 7 below summarises the numbers of animals, which were obtained from the Division of Livestock Services in Dhaka and District Livestock Office in Gazipur.

The difference in domestic cattle numbers versus general cattle numbers is due to commercial dairy livestock not being counted.

It is worth noting that Gazipur appears to have different relative national shares of cattle compared to poultry or cattle markets [26]; these differences would be worth exploring before confidently using the results of this scaling up method. For example, the results suggest that in Gazipur the potential from poultry farms is much more frequent than the rest of the country on average, and investment in these and related businesses in that district might provide better returns on investment (time, research and money) than elsewhere. Similarly, Gazipur seems to have a large number of markets per head of cattle, compared to the rest of the country: for interested investors, it might be particularly beneficial to concentrate on appropriate AD plant in Gazipur for that reason.

The multipliers in Table 7 (above) were used to scale up the results in Tables 3, 5 and 6 to yield the national estimates shown below in Table 8. There are several notable points. Firstly, the numbers of potential plants are huge: 2.3 million using domestic cattle dung alone. The large number implies the large number of households – almost one-to-one – which could benefit from cooking and lighting from AD. The disadvantages include the difficulty in setting up so many plants, including financing, expertise and maintenance issues.

6. Discussion of planning implications of the data

There are fewer poultry farms, but they are more appropriately serviced by medium and large plants able to provide for many families each. There are only 500 cattle markets expected nationally, but each with such a large capacity that commercial uses and electricity generation become competing options to householder cooking gas supply.

The breakdown by plant size is also useful for consideration. For example, the vast majority of all domestic plants would use cattle feedstock, implying that size might benefit from some specialised design features to make it more user-friendly and effective. For poultry, most of the plants must be medium-sized, so it might be worthwhile to modify designs for poultry litter use – but then it can be noted that almost ten times as many units are needed for cattle feed. Thus either of the two designs can develop, or, if necessary, the design might need to be dominated by the needs of cattle dung users. The same arguments apply to large units for poultry and cattle markets.

Viewing the same data from the perspective of which types provides the most energy gives a different picture. Table 9 below shows how domestic cattle make up 97% of the number of AD plant units required, but on a per-unit basis the cattle market AD plant will provide much more energy, as illustrated in Fig. 4. Thus, if an optimisation of energy is preferred for investment of time, resources or research, then cattle market plants might be the best starting point. This might be true for financiers desiring significant financial returns at fewer sites. On the other hand, to have a direct impact on the largest number of families, domestic plants running on cattle dung would be higher priority, and plans for financing, regulating and maintenance would have to be made – bearing in mind the circumstances of many smallholder families.

Table 9 illustrates the results categorised by feedstock source, showing the potential number of AD plants from cattle smallholdings, poultry farms and cattle market rice straw (larger numbers have been rounded).

Combining the AD capacity of three potential AD feedstocks, the daily potential AD capacity of Bangladesh is 240 million MJ which could come from 10.43×10^6 m^3 of biogas (1 m^3 biogas equals 23 MJ). This means the annual AD potential for Bangladesh from those potential feedstocks is 8.76×10^{10} MJ or 2.4×10^{10} KWh.

Table 7
Numbers of livestock and markets in Gazipur and Bangladesh, and the multipliers they produced to scale up district results to national figures (DLO – District Livestock Office DLS – Division of Livestock Service).

	Number of cattle (million)	Number of domestic cattle (million)	Number of Poultry birds (million)	Number of Cattle markets	References
Gazipur District	0.86	0.74	24.82	30	[24]
Bangladesh	22.97	20.67	221.39	500	[25]
Multipliers	26.72	27.83	8.92	16.67	

Table 9
Potential AD in Bangladesh categorised by potential feedstock and (i) by AD plant number and (ii) by energy contributions. Absolute numbers are 2.4 million units and 240 million MJ daily, respectively.

Feedstock	Percentage of total AD plant by number of units (%)	Percentage of total AD energy contribution by feedstock type (%)
Cattle	97	70
Poultry	3	16
Cattle market rice straw	0.02	14
Total	**100**	**100**

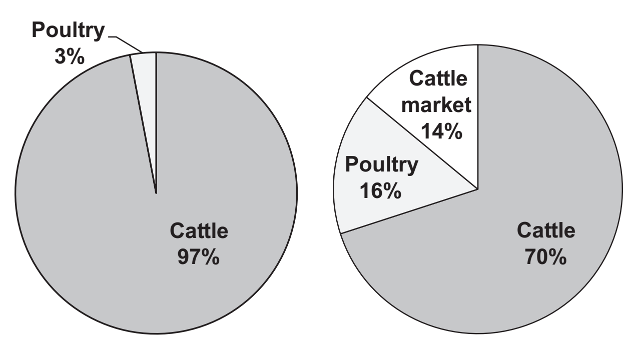

Fig. 4. An illustration of the difference in distributions of AD plant when considered in terms of (a) unit numbers and (b) percentage contributions to energy nationally.

Table 8
The numbers of potential AD plant units for different feedstock in Bangladesh, broken down into percentages by size for each feedstock.

	Small (< 2 m^3)	Domestic (2–5 m^3)	Medium (5–25 m^3)	Large (25–150 m^3)	Very large (1000–2000 m^3)	Extremely large (2000–7000 m^3)	Totals
Cattle	670,000 (29%)	1,341,000 (58%)	300,000 (13%)	n/a	n/a	n/a	**2,311,000 (100%)**
Poultry		4403 (7%)	40,000 (63%)	18,870 (30%)	n/a	n/a	**63,000 (100%)**
Cattle market rice straw	n/a	n/a	n/a		265 (53%)	235 (47%)	**500 (100%)**
Total numbers of units	670,000 (28%)	1,345,000 (57%)	340,000 (14%)	18,870 (14%)	265 (< 1%)	235 (< 1%)	**2,374,000 (100%)**

Table 10
Potential AD capacity is compared with the current status of AD.

Feedstock/Factor	Potential AD facilities	Current status
Cattle dung	2,310,000	35,000
Poultry litter	63,000	5000
Cattle market rice straw	500	0
Total	2,400,000	40,000
Present AD plant capacity (%)		**1.67**
Present AD energy capacity (%)		**0.67**

7. Final overview

The government of Bangladesh has a target to generate 5% of its total electricity using renewable energy technologies by 2015 and 10% by 2020 [27]. Ensuring that the potential of AD biogas production is fulfilled can play a vital role in meeting this target. A comparison between the potential AD capacity and the present reality is shown in Table 10.

All of the results in the sections above provide crucial information for planning for businesses, civic authorities and national policy making. By considering these results and information, the government can plan, NGOs and international development organisations can take initiatives, investors can see the relevance of funding, and the documentation of the GWP impact can assist in getting CDM credit. Integration of all these efforts could make a realistic opportunity for AD energy generation with sustainable management.

8. Conclusion and recommendation

8.1. Conclusion

This paper presents important primary data from surveys to determine the potential of common feedstocks for AD in Bangladesh. Domestic cattle in smallholdings, commercial poultry farms and daily cattle markets were surveyed and the results are presented in a matrix manner that allows interrogation by size, by feedstock, by number and by commercial/domestic use potential (see Section 6). The annual AD potential from those potential feedstocks is 8.76×10^{10} MJ or 2.4×10^{10} KWh, which is enough to meet the cooking needs of 6 million rural households (30 million people). The richness of the data provides invaluable information for strategic planning

Headline results include:

- As many as 2.3 million households could have their own units for lighting and cooking, and could potentially be set up via micro-financing.
- 340,000 medium sized units could provide business/entrepreneurial use.
- 19,000 units could provide large scale provision or electricity production.
- As few as 500 very large or extremely large units based at cattle markets could capture 14% of the overall potential from these feedstocks.

This is the first investigation of the feedstock from waste straw and dung from cattle markets in Bangladesh. It is identified here as a novel, significant and potentially very useful feedstock.

8.2. Recommendations for further work

A more critical analysis of realistic factors affecting biogas and methane yield should be undertaken for cattle market rice straw as a feedstock. Biogas and methane yields were determined in this research for rice straw that contained 15–20% of dung. The yield could be investigated using this feedstock with different percentages of cattle dung mixed with it. A significant amount of cow urine is mixed with cattle market rice straw waste.

Analysis of other feedstock types, such as food waste, water hyacinth, MSW and wastes mixed with animal manure, should be undertaken. The biogas yield capacity of these feedstocks, with different ratios of pre-mixing, could be investigated. A feasibility study could be undertaken to find out the barriers and bottlenecks of the implementation of AD programme in Bangladesh utilising various feedstocks. Further research could also investigate the efficiency of existing AD units.

It is important to undertake a detailed financial and social impact assessment of the various sized AD plants in order to understand the possible impacts on the rural population. The practical financial tools (e.g. microfinance) which could work for such a biogas programme in Bangladesh should be determined in detail.

Similar studies could be carried out for similar developing countries with rural areas; this work showed that it is feasible and effective for such a study to systematically determine the information gaps and lead to very useful information for future planning, both in detail and for an overview, for financial, environmental and social impacts.

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